

Regulatory Intervention and Energy Efficiency: A Cross-Country Assessment of the Energy Efficiency Directive of the European Union

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Abstract. Against the backdrop of global climate change and growing concerns over energy prices and security, improving energy efficiency has become an important policy goal for countries pursuing energy governance. Based on a difference-in-differences model, this paper uses World Bank data on 20 EU (European Union) member states and 12 non-EU OECD (Organization for Economic Co-operation and Development) countries from 2010 to 2023 to examine whether the EU's 2012 Energy Efficiency Directive (EED) promoted the strengthening of energy efficiency regulatory frameworks among member states, and to reflect the degree of improvement in energy efficiency regulatory frameworks across different countries. The results show that the EED has a significant positive effect on the energy efficiency regulatory score, and after controlling for economic development level, emission intensity, industrial structure, urbanization rate, and institutional quality, the energy efficiency score of EU member states increased by approximately 8.3 points compared to the non-EU group after the implementation of the EED. For the control variables, the rule of law index is significantly positively correlated with the energy efficiency score, while the proportion of industrial output value in GDP (Gross Domestic Product) has a negative correlation with it. This shows that the implementation capacity of the system and the industrial structure are important determinants of the adjustment of the regulatory framework. Overall, this paper claims that legally binding energy policies can effectively promote member states to enhance their energy efficiency regulatory frameworks, which have a positive effect on the environment.

Keywords: Difference-in-Differences, Energy efficiency regulation, Policy evaluation, Climate policy

1. Introduction

Over the past two decades, energy efficiency has become one of the core issues in global climate policies. In response to the increasingly urgent pressure to reduce greenhouse gas emissions, improving energy usage efficiency across different sectors like industries, buildings, and transportation is one of the most economically feasible paths for reducing emissions nowadays. Energy efficiency occupies an important place in the public policy agenda of most developed

countries, and it is linked to objectives of industrial competitiveness, energy security, and benefits, including the reduction of CO₂ emissions [1]. However, in order to turn this consensus into quantifiable policy outcomes, policies with legal binding force are needed to drive the process.

According to Deirmentzoglou et al., the EU's energy policy has undergone an evolution from being centered on energy security in the 1970s to gradually establishing a comprehensive policy framework that includes sustainable development, competitiveness, and supply security, which provides the foundation for EED [2]. The Energy Efficiency Directive (EED) was enacted by the European Union in 2012, and it was the first policy on energy efficiency within the European Union with legal effect. According to the EED, by 2020, all member states had to reduce total energy consumption by 20%, and the energy suppliers must save 1.5% of their sales each year, which was a shift in the direction of the EU's energy policy [3]. However, whether the EED truly benefited the energy efficiency ability of member states is worth discussing. Although those countries performed well in terms of energy efficiency scores, it is not sufficient to prove that the policy itself has had a causal effect on those countries' regulatory abilities.

Improving actual energy efficiency requires governments to establish robust regulatory frameworks, and what this paper examines is whether the EED caused EU member states to strengthen such frameworks or not. This study used the Difference-in-Differences model to compare the changes in energy efficiency scores of 20 EU member states and 12 other non-EU countries that were not affected by the EED before and after the policy to study the effect of the EED on the energy efficiency of member states. The data covers 32 countries and 14 years from 2010 to 2023, which form a balanced panel dataset with 448 observations, so as to provide useful insights for the energy transition of relevant EU countries.

2. Literature review

Academics have been discussing how to measure a country's energy efficiency for a long time. Herring defined energy efficiency as the ratio of energy service output to energy input [4]. However, relying solely on actual energy consumption data to assess policy effectiveness is limited because energy consumption is influenced by multiple factors, such as economic cycles and fluctuations in energy prices, making it difficult to accurately identify the net effect of the policy. Therefore, in recent years, researchers have begun to focus on indicators at the regulatory framework level. The energy efficiency score published by the World Bank is a representative tool among them, which reflects the maturity of a country's energy efficiency policy system by measuring the completeness of its mandatory standards and implementation mechanisms. Nevertheless, it is worth noting that critical policy studies have shown that the very concept of energy efficiency tends to neglect broader social and environmental tradeoffs since it is measured in EU policy [5]. Nam and Jin utilized the energy efficiency scores and the actual energy data from 109 countries from 2010 to 2017 to compare the differences between regulatory indicators and actual data in terms of carbon emission reduction effects, and they found that energy efficiency regulation has a positive effect on carbon emission reduction [6]. This study indicates that the energy efficiency score, as an indicator for measuring the policy and regulatory environment, can capture how well the adoption of policy is across countries effectively and is a very good quantitative tool for evaluating policies in different countries. However, the energy efficiency score has certain limitations. Urpelainen pointed out that this indicator may not fully reflect the differences in policy implementation at the actual level, because different countries have different national conditions [7].

Regarding the effectiveness of the EED policy, the existing literature mainly studies it from both micro and macro perspectives. From the micro perspective, using hourly smart-meter data from over

158,000 houses in Sacramento, Novan et al. found that California's mandatory building energy codes reduced electricity used for cooling by 8% to 13%, and that the mandated energy-saving requirements passed a cost-benefit test [8]. However, this study just focused on the impact of a single policy on actual energy consumption, and its sample was also limited to the residential sector in a specific region, which means it fails to reflect the overall regulatory framework of the EU policy. At the macro level, Filippini et al. used the stochastic frontier analysis method to estimate the energy efficiency levels of the residential sector in 27 EU member states, finding that economic incentives had a significant positive impact on improving energy efficiency, while information-based measures had no significant effect at all [9]. Although this study covered the EU-level policy framework, its analysis was limited to the residential sector, so it is possible that there are interference effects from other confounding factors on the policy's effectiveness. Additionally, Ringel conducted a questionnaire survey of 50 European institutional stakeholders, discovering that respondents generally held a relatively optimistic attitude towards the 2023 revised version of the EED, believing that the directive had made progress in the public sector and the construction field, but there were still deficiencies in its implementation in the transportation and agriculture sectors [4]. However, this study relied on questionnaire methods, so it is relatively subjective and lacks causal identification based on data. Notably, Cui et al. demonstrated that the DiD (Difference-in-Differences) method can be used to study environmental policies at the regional level [10]. The treatment group is cities that implemented the policy, while the control group is cities that did not implement it. This study shows that the DiD method can eliminate the interference of time trends and individual fixed effects effectively, and is highly applicable in the study of cross-regional causal effects of environmental policies.

Overall, although there are many comprehensive existing studies, there is still an important gap in the existing research: the existing literature either focuses on a single department, like transportation or construction, or just relies on questionnaire survey methods, which lack causal identification and do not take the overall energy efficiency regulatory framework of the country as the analytical object. To solve these gaps, this paper takes EED as a natural experiment at the country level and uses the double difference method to provide evidence at the cross-national level.

3. Data and descriptive statistics

The data used in this study are from the World Bank. The research sample consists of 32 countries and 14 years from 2010 to 2023, with 448 observations in total, and this paper presents a completely balanced panel dataset, in which each country has complete data records for 14 consecutive years.

For the selection of datasets, the policy studied in this paper is the 2012 EU Energy Efficiency Directive (EED). The treatment group consists of 20 EU member states at that time, while the control group comprises 12 non-EU OECD countries, which is the Organisation for Economic Co-operation and Development. The 20 EU member states were the countries to which the EED directly applied since 2012, and their treatment status was determined by whether they are in EU membership or not; while the control group countries are OECD members, which means they are comparable in terms of economic development level, institutional quality, and data availability with EU countries, but are not affected by the EED policy. In other words, they can show that the original development of EU countries' energy efficiency scores should have been presented without the effect of EED. To be specific, the 20 EU member states in the treatment group are: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Germany, Spain, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, and Sweden; the 12 non-EU OECD control countries are: Australia, Canada, Switzerland, Chile, Israel, Japan, Korea, Mexico, Norway, New

Zealand, Turkey, and United States. The starting year of the sample is 2010, which preserves a window period for testing the parallel trend assumption before the enactment of EED in 2012, and the ending year is 2023, which is the latest available year of data in the datasets.

The dependent variable of this paper is the energy efficiency score (*energy_eff*), which is used to measure how strong a country's energy efficiency regulatory framework is. It covers mandatory standards, financial incentives, and enforcement mechanisms of the energy efficiency policy system. The score ranges from 0 to 100; the higher the score is, the more complete the regulatory system is. The reason this paper chose energy efficiency score instead of actual energy consumption as the dependent variable is that the research question is focused on whether EED has promoted the improvement of the regulatory framework of member states, rather than directly decreasing energy consumption. Energy consumption is influenced by many factors, such as short-term economic cycles and fluctuations in energy prices, which make it difficult to identify the policy effects accurately.

There are five control variables in this paper. The log of per capita GDP (*ln_gdp_pc*) is used to control the impact of each country's economic development level on its energy regulatory capacity. The per capita CO₂ emissions (*CO2*) are used to control the emission intensity of each country; to be specific, countries with greater emission pressure may have a stronger motivation to strengthen energy regulation, rather than due to the influence of EED. The reason for controlling the proportion of industrial added value in GDP (*industry*) is that countries with a higher degree of industrialization have greater energy-saving demands and may also have a higher endogenous demand for the construction of regulatory frameworks. The urbanization level (*urban_pct*) also affects the density of energy infrastructure and the feasibility of regulation. Finally, the *rule_law* index is used to measure a country's institutional execution ability, directly determining whether energy efficiency policies can be effectively implemented. If a country's energy efficiency policy is implemented very well, it may be because the country itself has a good institutional execution ability for any policy, rather than because EED has improved the country's energy regulatory level.

Table 1. Description of variables

Variable Name	Description	Units
<i>energy_eff</i>	Energy Efficiency Score. Measures the comprehensiveness of a country's national energy efficiency regulatory framework, including standards, incentives, and enforcement mechanisms. Higher scores indicate stronger regulatory adoption.	Index, 0–100
<i>ln_gdp_pc</i>	Natural logarithm of GDP per capita. Controls for overall economic development, which may independently drive investment in energy efficiency infrastructure and regulations.	Log of current USD per capita
<i>co2</i>	CO ₂ emissions per capita. Controls for a country's emissions intensity, which may motivate governments to adopt stronger energy efficiency policies independently of the EED.	Tonnes per capita
<i>industry</i>	Industry value added as a share of GDP, including construction. Countries with larger industrial sectors may face greater regulatory pressure or higher returns to energy efficiency improvements.	% of GDP
<i>urban_pct</i>	Urban population as a percentage of total population. Derived by dividing urban population (persons) by total population. More urbanized countries tend to have denser energy infrastructure and different efficiency profiles.	%

Table 1. (continued)

rule_law	Rule of Law Index. Captures the quality of legal institutions and enforcement capacity, which affects a country's ability to implement and comply with energy efficiency regulations.	Index, 0–1 (higher = stronger rule of law)
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In terms of data processing, since the formats of the six original datasets are not uniform, this paper did data cleaning before merging. Among them, five datasets are stored in wide table format, with years as columns. Therefore, they are first converted to long table format so that each row corresponds to a country vs year observation. The urbanization rate is calculated by dividing the absolute number of urban population by the total population, and the GDP per capita is processed by taking the logarithm to reduce the influence of right-skewed distribution. In the original data, some countries had missing values in certain years. Model 1 reports the baseline DiD estimate using the full balanced panel of 448 observations, but after dropping 5 observations with missing values in the control variables, the regression sample consists of 443 observations in Model 2. Overall, after the cleaning is completed, the six datasets are merged into a main dataset using country codes and years as key values. The final regression sample covers 32 countries and 14 years from 2010 to 2023, with a total of 443 observations. The definition of control variables is detailed in Table 1.

According to the descriptive statistics in Table 2, the mean score of energy efficiency was 61.58, with a standard deviation of 18.27, a minimum value of 8.18, and a maximum value of 95.93. This shows that there were significant differences among countries in the construction of energy efficiency regulatory systems. The mean log of GDP per capita is 10.39, which corresponds to 32,500 US dollars, and this indicates that the sample countries were generally at a high income level. The mean value of CO₂ emissions per capita was 7.60 tons, the mean proportion of industrial output value in GDP was 24.69%, the mean urbanization rate was 77.18%, and the mean legal index was 0.893. These statistics reflect the overall strong institutional implementation ability of the sample countries.

Table 2. Descriptive statistics of variables

Variable Name	N of obs	Mean	Std. Dev.	Min	Max
energy_eff	443	61.58	18.268	8.179	95.926
ln_gdp_pc	443	10.388	18.268	8.179	95.926
co2	443	7.598	3.363	3.383	18.297
industry	443	24.691	5.749	13.414	49.129
urban_pct	443	77.183	10.789	51.842	97.36
rule_law	443	0.893	0.164	0.134	0.999
Treatment (EU member)	443	0.632	0.483	0	1
Post-EED (year ≥ 2012)	443	0.856	0.352	0	1
DiD (Treat × Post)	443	0.542	0.499	0	1

Table 3. Mean comparison by group (EU vs. Non-EU) pretreatment period (2010–2011) for baseline balance

Variable Name	EU (treat=1)	Non EU (treat=0)	Difference	P value
energy_eff	41.180	41.202	−0.022	0.995
ln_gdp_pc	10.289	10.433	−0.143	0.412

Table 3. (continued)

co2	7.815	9.930	-2.115	0.024*
Industry	24.041	27.408	-3.366	0.026*
urban_pct	72.521	82.349	-9.828	0.000***
rule_law	0.917	0.900	0.017	0.611

Table 3 shows the comparison test of the mean values of various variables between EU countries and non-EU countries before the EED policy. The results show that the energy efficiency benchmark levels of the two groups of countries before the policy were almost the same. The mean value of EU was 41.18, and that of non-EU was 41.20, with $p = 0.995$. The p-value for the logarithm of GDP per capita was 0.412, and the p-value for the legal index was 0.611. There were no significant differences. However, the CO₂ emissions per capita of non-EU countries (9.93 tons vs. 7.82 tons and $p = 0.024$), the proportion of industrial output value in GDP (27.41% vs. 24.04% and $p = 0.026$), and the urbanization rate (82.35% vs. 72.52% and $p < 0.001$) were all significantly higher than those of EU countries. Therefore, it is necessary to include these variables in the regression.

4. Model description

4.1. Empirical strategy and the selection of the model

This paper uses the Difference-in-Differences (DiD) model to identify the causal effect of the EED, which was enacted in 2012, on the energy efficiency regulatory framework of member states. The fundamental logic is to compare the changes in energy efficiency scores of EU member states, which is the treatment group, and non-EU OECD countries, which is the control group, before and after the implementation of the policy, to get the net effect of the policy itself.

EED is highly suitable for use in the analysis of the DID model. That's because, firstly, EED is issued by the EU at the national level and has the same binding force for all member states. No single country actively chooses whether to accept policy intervention based on its own energy efficiency performance, which ensures that the policy shock is exogenous and consistent for those member states. Furthermore, the cut-off year of EED is very clear. Whether a country is an EU member state was determined before 2012, so the grouping of the treatment group will not be affected by the changes in the dependent variable after the implementation of EED. Additionally, the dependent variable energy efficiency score is a continuous variable ranging from 0 to 100, so a linear regression model is more appropriate. If the dependent variable is a binary variable, such as whether EED is adopted or not, then a logit or probit model should be used; but for this paper, the linear fixed effects model can directly estimate the treatment effect, so a non-linear model is not necessary.

4.2. Model specification and fixed effects estimation

The DID regression equation(1) is as follows. In this model, i represents the country and t represents the year from 2010 to 2023. $Treat_i * Post_t$ is the DiD interaction term and has a coefficient β , which is the core parameter of this study, which measures the average treatment effect of EED on the energy efficiency score of EU member states; μ_i is the country fixed effect, and λ_t is the year fixed effect.

$$Energy_eff_it = \alpha + \beta(Treat_i \times Post_t) + \gamma X_it + \mu_i + \lambda_t + \varepsilon_it \quad (1)$$

This paper uses fixed effects rather than random effects. From the Hausman test results, $\chi^2(19) = 36.14$, $p = 0.010$, in which the degrees of freedom are 19 because the six time-varying coefficients plus 13 year fixed effects are included in the specification, and reject the null hypothesis of random effects at the 5% significance level. Therefore, the individual effects at the national level are systematically correlated with the explanatory variables. The fixed effects estimator is more consistent than the random effects estimator in this case because of various unobservable factors in each country, such as energy regulatory traditions, political systems, and historical relationships with the EU. These factors are likely to determine whether a country becomes an EU member, which means $treat = 1$ or not, and affect its energy efficiency level as well. To be specific, if a country has a strong energy regulatory tradition, this may be related to its willingness to join the EU and also promote its energy efficiency improvement. Therefore, if using random effects, this unobservable heterogeneity will be included in the error term, leading to estimation bias. Therefore, use fixed effects and set independent intercept terms for each country to absorb all individual differences that do not change over time completely, thereby making sure of the accuracy of the results. It is worth noting that, regarding the validity of the estimators, when there is a correlation between individual effects and explanatory variables, the fixed effect estimator is consistent. After using clustered robust standard errors, the fixed effect estimator becomes the optimal linear unbiased estimator (BLUE), so the estimation results are reliable.

Furthermore, need to address the potential omitted variable bias in this study. If there are unobservable factors that affect both whether a country joins the EU and its energy efficiency score, then the DiD estimation of β will be biased. For example, if a country already has a strong environmental awareness, this could both make it more inclined to join the EU and also enable it to independently improve energy efficiency regulation. This would lead to an overestimation of the effect of EED itself. However, for this study, the country fixed effects absorb all the country-level characteristics that do not change over time; the year fixed effects control all the global shocks that countries face simultaneously in the same period; and the five control variables further control the differences between countries over time, including economic development level, emission intensity, industrial structure, urbanization rate, and institutional quality. Although it is impossible to completely eliminate the influence of all omitted variables, these three controls significantly reduce the possibility of the omitted variable bias in this study.

4.3. Parallel trends assumption and event study

The basic assumption for the DiD model is the parallel trends assumption. To be specific, if there is no EED, the energy efficiency scores of EU countries and non-EU countries should increase in the same trend. In other words, the treatment effect β identified by DiD reflects the additional change caused by the policy shock, rather than the systematic trend differences that already existed in the two groups of countries before the policy. It is worth mentioning that the difference between the parallel trends assumption and Fixed effect is that the parallel trends assumption states that, in the absence of EED, the upward trend of energy efficiency scores for both groups is supposed to be the same, which cannot be guaranteed by FE because this trend changes over time.

This paper provides evidence supporting the parallel trends assumption in two ways. First of all, according to Table 3, by comparing the averages for 2010–2011, it shows that the energy efficiency benchmark levels of the two groups of countries before the policy implementation were almost the

same. To be specific, the average of EU is 41.18, and the average of non-EU is 41.20, with $p = 0.995$, which shows that there was no systematic level difference between the two groups before the policy shock.

Furthermore, this paper also uses an event study estimation by decomposing the single DiD interaction term into annual treatment effect coefficients, and is shown as equation (2):

$$\begin{aligned} Energy_eff_it = & \alpha + \sum_k \beta_k (Treat_i \times I[year = k]) + \gamma X_it \\ & + \mu_i + \lambda_t + \varepsilon_it \end{aligned} \quad (2)$$

Since 2012 was the first year of the EED implementation, take 2011 as the base year and estimate the treatment effect β_t for each year from 2010 to 2023 relative to that of 2011. If the parallel trends assumption holds, β_{2010} should be statistically insignificant and economically close to zero, which means there was no differential trend between the treatment group and the control group before the policy; if the coefficients after the policy implementation (years after 2012) remain significantly positive, then say the EED has a positive effect on the energy efficiency score of each country. The results show that $\beta_{2010} = -1.661$ is statistically insignificant with $p = 0.270$; after the enactment of EED, the coefficients turn positive and become statistically significant from 2014, which is consistent with the parallel trends assumption. The coefficient graph is shown in Figure 1. The event studies estimate the EED's effect on energy efficiency scores. Reference year: 2011. The red line is the EED enactment year, 2012. The dots represent point estimates and bars represent 95% confidence intervals. Standard errors are clustered by country.

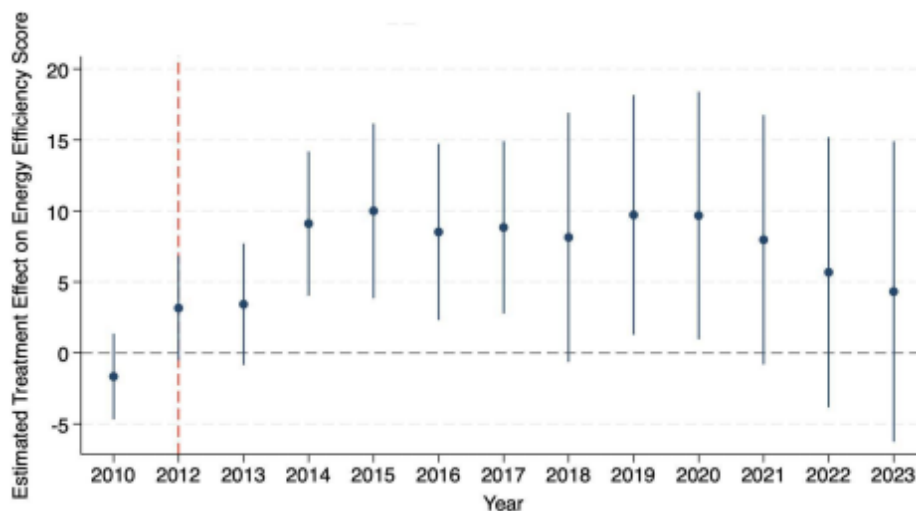


Figure 1. EU EED effect over time

4.4. Placebo test

To further verify the parallel trend assumption, this paper also constructs the placebo test. By using the data before the policy implementation, and setting 2011 as the new policy cut-off point ($Post_t = 1$ if $year \geq 2011$), and having a new DiD interaction term, which is $did_placebo = Treat_i \times 1(year=2011)$. That's because before the EED was enacted, neither EU nor non-EU countries were subject to the EED constraint, so the theoretical energy efficiency changes of the two groups should have no systematic differences. If the new DiD coefficient is statistically significant, it means that there was already a different trend between the two groups before the EED, and thus does not

conform to the parallel trend assumption. This paper finds that the estimated placebo coefficient of 1.762($p = 0.237$) is statistically insignificant, which means that no differential trend existed between the two groups prior to the EED, and the parallel trends assumption is confirmed.

5. Result

5.1. Regression result

The main estimation results of the DID model are in Table 4. There is only the DiD interaction term and the year fixed effect without any control variables in model 1, with an estimated treatment effect of 7.460 points and $p = 0.028$. It is statistically significant at the 5% level, which means the increase in energy efficiency scores for EU member states is already statistically significant even if the model does not add any other control variables, and the average increase in energy efficiency score in those EU countries is about 7.5 points higher than that of non-EU countries. After adding all the control variables in model 2, the DiD coefficient slightly rises to 8.271 points with $p = 0.002$, which is higher both economically and in statistical significance. To be specific, after controlling for differences in economic development level, emission intensity, industrial structure, urbanization rate, and institutional quality, the estimated effect of EED is more precise and more significant. The intra-group R^2 increases from 0.751 in model 1 to 0.786 in model 2, which shows that the addition of control variables helps explain the changes in the energy efficiency score within countries better. Overall, EED boosted the energy efficiency regulatory score of EU member countries by approximately 8.3 points compared to those of non-EU countries. Since the energy efficiency score ranges from 0 to 100, 8.3 is quite a significant effect.

For control variables, according to Table 4, there are two control variables that have a significant impact on the model. The proportion of industrial output in GDP is significantly negatively correlated with the energy efficiency score ($\beta = -0.496$, $p = 0.020$), which shows that countries with a larger proportion of the industrial sector have lower scores in the integrity of the regulatory system. A possible explanation is that the larger the industrial interest group is, the less space there is for policies to adjust. The rule of law index is significantly positively correlated with the energy efficiency score ($\beta = 52.594$, $p = 0.039$), indicating that countries with stronger system implementation capabilities can more effectively implement and maintain energy efficiency regulations.

Table 4. Regression results

Variables	Model 1: Basic DiD	Model 2: Full Controls
DiD (Treat $\times$ Post)	7.460** (3.242) $p = 0.028$	8.271*** (2.384) $p = 0.002$
Log GDP per capita	---	-4.815 (7.642) $p = 0.533$
CO2 per capita (tonnes)	---	2.089 (1.230) $p = 0.100$
Industry value added (% GDP)	---	-0.496* (0.203) $p = 0.020$

Table 4. (continued)

Urban population (%)	---	1.421 (1.007) p = 0.168
Rule of Law Index	---	52.594* (24.452) p = 0.039
Country FE	Yes	Yes
Year FE	Yes	Yes
Controls	No	Yes
Within R2	0.751	0.786
N	448	443

5.2. Robustness tests result

The results of the Hausman test from Table 5 and the robustness test from Table 6. Firstly, after excluding the years during the COVID-19 pandemic, from 2020 to 2021, the DiD coefficient is 7.739 with $p = 0.002$, which is almost the same as the baseline estimate of 8.271, indicating that the main conclusion is not affected by various economic factors during the pandemic. Secondly, the placebo test uses the data before the policy implementation and sets 2011 as a new policy cutoff point. The estimated new DiD coefficient is 1.762 with $p = 0.237$, which is not statistically significant. This result shows that before the implementation of the EED, the energy efficiency score of the treatment group and the control group developed in similar track, and proves the parallel trend assumption.

Table 5. Hausman test (FE vs. RE)

Variables	Result
$\chi^2(19)$	36.14
Prob > χ^2	0.0102
Conclusion	Reject RE; FE preferred ($p < 0.05$)

Table 6. Robustness checks

Variables	Excl. COVID (2020–21)	Placebo Test
DiD (Treat $\times$ Post)	7.739*** (2.226)	---
Placebo DiD (fake 2011 cutoff)	---	1.762 (1.461)
Sample	Excl. 2020–2021	2010–2011 only
N	379	64

It should be noted that the results of this paper are highly consistent with the previously mentioned existing literature on the effectiveness of mandatory energy efficiency regulations. Filippini et al. found that binding energy efficiency performance standards have a positive impact on the energy efficiency of EU member states [9], which is consistent with the positive DiD coefficient in this paper. Novan's research finds that mandatory standards can produce more lasting energy-saving effects than voluntary ones [8]; this paper also reaches the same conclusion. The policy-

binding force of EED is a key factor in the source of its policy efficiency. At the same time, since the variance in the energy efficiency scores within the sample is still large, this paper also agrees with the findings of Ringel, that is, although EED has promoted progress in the regulatory aspect of EU countries, there are still differences in the implementation quality among member states [3].

6. Conclusion

In summary, this paper examines whether the 2012 EU Energy Efficiency Directive (EED) has positively affected member states in strengthening their energy efficiency regulatory frameworks. This paper uses the energy efficiency score from the World Bank as the measurement indicator, and implements a difference-in-differences model to compare the energy efficiency scores of 20 EU member states with those of 12 non-EU OECD countries from 2010 to 2023. The result states that the EED has a significant positive effect on the energy efficiency regulatory score. To be specific, the energy efficiency score of EU member states increased by approximately 8.3 points after the implementation of the EED since 2012, compared with the control group. This conclusion is still stable after adding control variables and excluding years and macroeconomics affected, among other robustness tests.

The results of this paper provide insights for the national policy in reality. Firstly, a mandatory legal framework is more effective than voluntary agreements. As EED is the first legally binding directive in the EU, it significantly improved the energy efficiency regulatory level of member states, leading to the conclusion that if only encouraging countries to voluntarily adopt energy policies, the effect might not be as good as a mandatory policy. Therefore, for other international organizations that hope to promote energy transformation, formulating binding common standards is more likely to bring changes than just issuing guidance opinions. Secondly, the effectiveness of policies depends on a country's institutional implementation capacity. The higher the rule of law index of a country, the higher the energy efficiency score. This shows that even though there are good policies, it is still important whether they can be implemented effectively. Therefore, for member states with relatively weak institutional foundations, relying solely on mandatory constraints is not enough. It is also necessary to provide supporting supervision mechanisms to help these countries truly implement the policies. At the same time, countries with a heavy industrial structure face greater difficulties in promoting energy regulation. This paper found that the higher the proportion of industry in a country, the lower the energy efficiency score. This might be because large industrial interest groups have stronger resistance to strict energy regulations. Therefore, when formulating policies, more transitional time or subsidies should be given to such countries to reduce the resistance to policy implementation.

However, this study still has limitations to some extent. First of all, the energy efficiency score measures the completeness of the regulatory framework rather than the actual energy consumption, and the conclusions of this paper reflect changes at the level of regulatory adoption rather than actual energy saving results. Although this paper proves that policies can make a country's regulatory framework stronger, for the environment, the ultimate expected result is lower energy consumption. Therefore, whether a stronger regulatory framework can truly have a positive protective effect on the environment is still an issue that needs to be tested. Secondly, the dataset itself also has limitations. The energy efficiency score measures how well those countries adopt policies at the regulatory framework level, rather than the actual implementation strength or final effect of the policies. To be specific, a country's energy efficiency score may be high, but its actual law enforcement might be weak. Therefore, the conclusion of this paper reflects that EED has promoted member states to

improve energy efficiency regulations at the institutional level, but it cannot directly prove that these regulations have been effectively implemented in reality.

Additionally, for the placebo test, due to the limitations of the dataset, the preprocessing window period of this paper is only 2010 and 2011, which makes the verification of the parallel trend assumption limited to some extent. Therefore, future research can use actual energy consumption as the outcome variable to test whether the improvement at the regulatory level can translate into real efficiency improvement. At the same time, as data becomes gradually available after 2023, future research can evaluate the effect of the 2023 revised energy efficiency directive compared to the original framework in 2012.

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